ESE Research Strategy: -- selected charts --

Jack Kaye
ESE Research Division

Presented to ESSAAC

December 5, 2000

ESE Strategy Revised List of Questions

*How is the global Earth system changing**?(Variability)***

- How are global precipitation, evaporation, and the cycling of water changing?
- How is the global ocean circulation varying on interannual, decadal, and longer time scales?
- How are global ecosystems changing?
- How is stratospheric ozone changing, as the abundance of ozone-destroying chemicals decreases and new substitutes increases?
- What changes are occurring in the mass of the Earth's ice cover?
- What are the motions of the Earth and the Earth's interior, and what information can be inferred about Earth's internal processes**?**

What are the primary forcings of the Earth system? (Forcing)

- What trends in atmospheric constituents and solar radiation are driving global climate?
- What changes are occurring in global land cover and land use, and what are their causes?
- How is the Earth's surface being transformed and how can such information be used to predict future changes?

How does the Earth system respond to natural and human-induced changes?(Response)

- What are the effects of clouds and surface hydrologic processes on Earth's climate?
- How do ecosystems respond to and affect global environmental change and the carbon cycle?
- How can climate variations induce changes in the global ocean circulation?
- How do stratospheric trace constituents respond to change in climate and atmospheric composition?
- How is global sea level affected by climate change?
- What are the effects of regional pollution on the global atmosphere, and the effects of global chemical and climate changes on regional air quality?

What are the consequences of change in the Earth system for human civilization?(Consequences)

- How are variations in local weather, precipitation and water resources related to global climate variation?
- What are the consequences of land cover and land use change for the sustainability of ecosystems and economic productivity?
- What are the consequences of climate and sea level changes and increased human activities on coastal regions?

How well can we predict the changes to the Earth system that will take place in the future?(Prediction)

- How can weather forecast duration and reliability be improved by new space-based observations, data assimilation, and modeling?
- How well can transient climate variations be understood and predicted?
- How well can long-term climatic trends be assessed or predicted?
- How well can future atmospheric chemical impacts on ozone and climate be predicted?
- How well can cycling of carbon through the Earth system be modeled, and how reliable are future atmospheric concentrations of carbon dioxide and methane by these models?

Table of Observational Parameters: Prediction

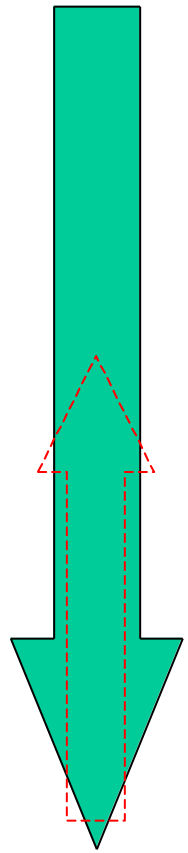
Parameter / Question	Implementation Detail	In Situ Measurement	Technical Readiness	Operational Potential	Partnership Potential
Tropospheric Winds (P1)	Active Doppler lidar remote sensing	rawinsondes (NOAA, WWW)	Technical developments, demonstration needed	Very high, when demonstrated	Commercial data purchase possible
Ocean Surface Winds (P1)	Active µwave technique	ships, buoys (NOAA. WWW)	Demonstrated by NSCAT & SeaWinds	NPOESS requirement nominally fulfilled by passive sensor	Seawinds cooperation with Japan; EUMETSAT data acquis.
	Passive µwave radiometry/polarimetry		Windsat/Coriolis demonstration funded by DOD, USN, NPOESS	NPOESS commitment	Possible
Global Precipitation (P1)	Requires Constellation for Good Time Resolution	Rain gauges, weather radar (NOAA, WWW)	Demonstrated via TRMM	Limited	Excellent – several needed
Freeze-Thaw Transition (P1)	Need to assess in all cloud and vegetation conditions	Not a routine measurement	Awaiting demonstration	Desired; subject to operational viability	Possible
Lightning Rate (P1)	Requires geostationary implementation for temporal resolution	Sferics	Demonstrated by OTD and LIS	Could be implemented on future GOES	Possible
Soil Moisture (P1, P2)	Spatial resolution and ability to penetrate vegetation are crucial	neutron probes, lysimeters (USDA, USGS, FAO)	Approaching readiness (done from aircraft)	Highly desired, subject to operat. viability	Possible
Sea Surface Temperature (P2)	Both IR and µwave observations needed for all-weather measurement	ships, buoys (NOAA, WWW)	Excellent	NPOESS Commitment	EUMETSAT coordination
Sea Level Height (P2)	Prefer non-polar orbit to avoid tidal aliasing	Tide gauges; Global Geodetic Network for reference frame	Demonstrated	Included on one NPOESS sat. but polar orbit is problematic	Continuation of past partnership likely
Deep Ocean Circulation (P3)	Requires *in situ* oceanographic observations	Ships and ARGO floats (NOAA, NSF)	WOCE, GODAE research projects provide initial data base	Operational Global Ocean Observing System is being envisaged	Multi-agency, international cooperation is anticipated
Total Column Ozone (P4)	High long-term accuracy needed for trend studies	Dobson, Brewer, FTIR, UV/VIS (NASA, NOAA)	Excellent	NPOESS commitment	EUMETSAT coordination
Trends in Carbon sources and sinks (P5)	CO_2 and CH_4 column mapping is most promising approach	Flask network (NOAA), Ameriflux/FluxNet (DOE, USDA, NASA)	Experimental technique; needs further development	Unlikely	Possible
Land Cover/Land use Change (P5)	High spatial resolution (few meters) crucial	Land cover maps (USGS), Veg. Inventories (DOI, USDA)	Excellent, need to reduce cost	Commercial data purchase likely	Possible with US industry

Getting From Science Questions to Systematic Missions

- Goal is to implement the Research Strategy
  - Provides questions, required data sets, and priority criteria
- Science questions should be addressed in a logical order
  - Reflecting the progression from variability through prediction on the one hand, and the priority order of subquestions within each category on the other
  - Presented in table form, implies upper left to lower right
- Priority criteria in the Research Strategy are applied to the questions (down arrow) to identify candidate missions, then to the candidate missions (up arrow) to set priorities
- An end-to-end approach of providing leadership and investing in observational information systems, scientific research, modeling and data analysis to obtain answers to questions

Establishing Priorities

Science Priority Criteria



- Science Return
- Benefit to Society
- Mandated Program
- Appropriate for NASA
- Partnership Opportunity*
- Technology Readiness
- Program Balance
- Cost/Budget Context

* Includes potential for handoff to operational systems

Implementation Priority Criteria

Logical Progression of Science Questions is Generally From Upper Left to Lower Right

Variability	Forcing	Response	Consequence	Prediction
Precipitation, evaporation & cycling of water changing?	Atmospheric constituents & solar radiation on climate?	Clouds & surface hydrological processes on climate?	Weather variation related to climate variation?	Weather forecasting improvement?
Global ocean circulation varying?	Changes in land cover & land use?	Ecosystem responses & affects on global carbon cycle?	Consequences in land cover & land use?	Predict transient climate variations?
Global ecosystems changing?	Surface transformation?	Changes in global ocean circulation?	Coastal region change?	Trends in long term climate?
Stratospheric ozone changing?		Stratospheric trace constituent responses?		Future atmospheric chemical impacts?
Ice cover mass changing?		Sea level affected by climate change?		Future concentrations of carbon dioxide and methane?
Motions of Earth & interior processes?		Pollution effects?		

Earth Science Enterprise
National Aeronautics and Space Administration

Candidate Systematic Missions

Derived from Measurement Requirements Related to Selected Science Questions	*Scrubbed Considering Other Sources*	*Ordered by Need Date to Achieve Continuity*	*Consolidated Based on Like Measurement Technologies*
Land Cover Inventory	Land Cover Inventory	Land Cover Inventory	Land Cover Inventory -- Landsat
Land Surface Vegetation	Land Surface Vegetation	Land Surface Vegetation	Land Surface Vegetation -- NPP
Atmos. Temp & Humidity	Atmos. Temp & Humidity	Atmos. Temp & Humidity	Atmos. Temp & Humidity -- NPP
Global Precipitation	Global Precipitation	Global Precipitation	Global Precipitation
Ocean Surf. Topog.	Ocean Surf. Topog.	Ocean Surf. Topog.	Ocean Surface Topography
Solar Irrad. Monitor	Solar Irrad. Monitor	Ocean Surface Wind	Ocean Surface Wind
Total Column Aerosol	Total Column Aerosol	Solar Irrad. Monitor	Solar Irradiance Monitor
Aerosol Vertical Profile	Aerosol Vertical Profile	Aerosol Vertical Profile	Ozone/Aerosol Vertical Profiles
Ocean Color	Ocean Surface Wind	Ozone Vertical Profile	Total Column Ozone/Aerosol
Energy Budget at TOA	Total Column Ozone	Total Column Ozone	Strat. Constituents/Temperature/ H_2O
Ocean Surface Wind	Ozone Vertical Profile	Total Column Aerosol	Land Ice Topography
Total Column Ozone	Land Ice Topog.	Stratospheric Constit.	
Ozone Vertical Profile	Stratospheric Constit.	Stratospheric T/ H_2O	
Land Ice Topog.	Stratospheric T/ H_2O	Land Ice Topog.	
Stratospheric Constit.			
Stratospheric T/ H_2O			

- Depending on arrangements with partners, one or more missions could “come on” or “come off” the list
  - Solar irradiance - IPO consideration of earlier flight of TSIM (copy of instrument on SORCE)
  - Ozone - IPO desires to do early test of OMPS instrument (or part thereof) - could eliminate need for NASA measurement (esp. if mapping part of OMPS tested on suitable orbit) - note also commitment to earlier flight of NPOESS-C1 could eliminate requirement for NASA total ozone/aerosol measurement in ~2008
  - Ocean color - if NPOESS “third platform” were to appear unlikely, morning observations of ocean color might need to be revisited

Missions candidates from this list are still under discussion; to be determined in the FY02 budget process

Table of Observational Parameters: Variability

Parameter/ Question	Implementation Details	In Situ Measurements	Technical Readiness	Operational Potential	Partnership Potential
Atmospheric Temperature (V1)	Passive Sounding	Radiosondes (NOAA, WWW, NASA, NDSC)	Excellent	NPOESS commitment	EUMETSAT coordination
	Active Sounding (GPS)	Global GPS network	Full demonstration needed	NPOESS commitment	EUMETSAT coordination
Atmospheric Water Vapor (V1)	Passive Sounding	Radiosondes, Ly-α, µwave (NASA, NOAA, WWW)	Satisfactory	NPOESS commitment	EUMETSAT coordination
Global Precipitation (V1)	Requires 6-8 satellite constellation for time resolution	Rain gauges, weather radar (NOAA, WWW)	Demonstrated by TRMM and passive µwave imagers	TBD	Excellent – several needed
Soil Moisture (V1)	Requires relatively low (L-band) _ wave frequency	neutron probes, lysimeters (USDA, USGS, FAO)	Very large real or synthetic antenna to be demonstrated	Possible	TBD
Ocean Surface Topography (V2)	Prefer non-polar orbit to avoid tidal aliasing	Tide gauges (Global Geodedic Network)	Demonstrated. Development needed for denser coverage	Included on one NPOESS sat. but polar orbit is problematic	Continuation of current partnerships likely
Ocean Surface Winds (V2)	Active µwave technique preferred	ships, buoys (NOAA, WWW)	Demonstrated by NSCAT and Seawinds	NPOESS need nominally fulfilled by passive sensor	Seawinds and follow-on cooperation with Japan
Sea Surface Temperature (V2)	Both IR and microwave needed for all-weather observation	ships, buoys (NOAA, WWW)	Excellent	NPOESS Commitment	EUMETSAT coordination
Sea Ice Extent (V2)	Microwave radiometry needed for all-weather measurements	Ships, airborne reconnaissance (Navy, USCG, NOAA)	Excellent	NPOESS Commitment	NASDA cooperation
Terrestrial Primary Productivity (V3)	1 km or better resolution needed	Crop, forest inven. (USDA, FAO, LTER (NSF), GTOS	Excellent	NPOESS commitment	EUMETSAT coordination
Marine Primary Productivity (V3)	Very precise inter-calibration is essential	NASA-SIMBIOS time series studies	Demonstrated	Partially provided by NPOESS	Cooperation with Japan, Europe possible
Total Column Ozone (V4)	High long-term accuracy needed for trend studies	Dobson, Brewer, FTIR, UV/VIS (NASA, NOAA)	Excellent	NPOESS commitment	EUMETSAT coordination
Ozone Vertical Profile (V4)	Good vertical resolution needed near tropopause	Ozonesondes, lidar, µwave , IR, (NASA, NOAA)	Excellent	NPOESS commitment	Coordination potential exists
Ice Surface Topography (V5)	Excellent vertical resolution and accuracy needed for mass balance studies	GPS (NASA, NSF)	ICEsat lidar altimetry demonstration pending	Not currently an operational requirement	Coordination with European radar altimetry satellite
Gravity Field (V6)	Requires extreme precision	Geodetic networks	GRACE demo. pending	DOD interest in precise geoid	Possible
Terrestrial Reference Frame (V6)	Derived mainly from ground observation and precision satellite tracking	SLR and GPS networks	Excellent	Multi-agency infrastructure	Multi-national ground network
Motions of the Earth's Interior (V6)	Inferred from mult. measurements -- space/ground based	SLR, GPS, VLBI networks, magnetometer obs.	Excellent	Multi-agency infrastructure	Excellent for flights of opportunity

Table of Observational Parameters: Forcing

Parameter / Question	Implementation Details	In Situ Measurements	Technical Readiness	Operational Potential	Partnership Potential
Total Solar Irradiance (F1)	High absolute accuracy, overlap of successive records required	global surface networks (BSRN, WRDC, SURFRAD)	Excellent	NPOESS Commitment	Possible
Solar UV Irradiance (F1)	Need for spectral resolution and good radiometric accuracy	USGCRP UV network, NDSC (multiagency)	Excellent	NPOESS measurement planned	Strong history of cooperation
Stratospheric Aerosol Distribution (F1)	Good vertical resolution and large dynamic range required	Lidar, backscatter-sondes (NASA, NOAA, NSF)	Excellent	NPOESS meas. possible but resolution is problematic	Possible
Total Aerosol Amount (F1)	Global coverage over ocean and land needed	AERONET, USDA network, NOAA/BSRN, DOE/ARM	Excellent	NPOESS Commitment	Possible
Aerosol Properties (F1)	Need in situ and ground-based measurements	AERONET, NOAA/CMDL, airborne aerosol spectrometers	Further development needed for space measur.	TBD	Possible, important for ground-based measurements
Sfc. Trace Gas Concentration (F1)	Ground-based measurements fulfil requirements	NASA AGAGE, NOAA flask network and CO_2 meas.	Need simpler instruments with better time resolution	NOAA flask sampling network, NASA AGAGE	Helps support ground network
Volcanic Gas & Ash Emissions (F1)	Global observation of ash and gas plumes	In situ optical calibration	Further progress needed to characterize tropospheric constituents	Significant on account of impact on aviation	Possible
Fire Occurrences (F2)	Global observation of infrared and vis/near-ir; hyperspectral for fuel load	Aeronet (NASA), burn scar inven. (USFS, int'l.), In situ optical calib.	Excellent	Augmented NPOESS EDR requirement	Augmented NPOESS EDR requirement
Trace Gas Sources (F2)	CO_2 column mapping is greatest priority	Flask network (NOAA), Ameriflux (DOE, USDA, NASA), FluxNet	Technical developments needed for exploratory mission	Unlikely	TBD
Land Cover/ Land Use Inventories (F2)	High spatial resolution required (few tens of meters)	Land Cover Maps (USGS), Veg. Inventories (DOI, USDA)	Excellent, need to reduce cost	Commercial data purchase likely	Possible with US industry
Surface Stress and Deformation (F2)	Special focus on active earthquake and volcanic regions	Regional GPS networks, geological obs.	Excellent	Joint support of ground arrays by local agencies	multi-national support for ground arrays

Table of Observational Parameters: Response

Parameter / Question	Implementation Detail	In Situ Measurements	Technical Readiness	Operational Potential	Partnership Potential
Cloud System Structure (R1)	Multispectral visible and IR radiometry	Radiosondes, lidar (NASA, NOAA, FAA)	Excellent	NOAA & NPOESS commitment	EUMETSAT and Japan's ADEOS/GLI
Cloud Particle Properties and Distribution (R1)	Active sensor to resolve three-dimensional structure	none	Demonstration of cloud radar and lidar pending	Desirable; subject to operational viability	DOD is contributing to Cloudsat project
Earth radiation Budget (R1)	Broadband radiometry	none	Excellent	Planned on NPOESS	Possible
Soil Moisture (R1)	Spatial resolution and ability to penetrate vegetation are the issues	neutron probes, lysimeters (USDA, USGS, FAO)	Approaching readiness (done from aircraft)	Highly desired; subject to oper. viability	Likely with European Space Agency
Snow Cover & Accumulation (R1)	Need to assess snow depth or water equivalent quantitatively	Snow transects (NOAA/NWS)	Awaiting demonstration	NPOESS commitment for snow cover	Possible
Freeze-Thaw Transition (R1)	Need to assess in all cloud and vegetation conditions	Not a routine measurement	Awaiting demonstration	Desired; subject to operational viability	Possible
Biomass (R2)	Based on resolving canopy vertical structure; requires active lidar sensor	Crop/Timber yield (USDA, DOI), carbon database (DOE)	Demonstration pending (VCL)	TBD	Possible
Marine Productivity in Coastal regions (R2)	High spatial and temporal resolutions needed to resolve specific events	NASA-SIMBIOS; Coastal bio-optics (NOAA, EPA)	Excellent	Possible NPOESS derived product	International product inter-comparison
Carbon Sources and Sinks (R2)	CO_2, CH_4 column mapping is most promising approach;	Flask network (NOAA), Ameriflux/Flux Net (DOE, USDA, NASA)	Experimental technique, needs further develop.	Unlikely	Possible
Sea Surface Salinity (R3)	Very high radiometric precision needed for passive μwave observation	Ships and moored/drifting buoys (NOAA/NSF)	Approaching readiness (done from aircraft)	Unfulfilled NPOESS requirement	Likely with European Space Agency
Sea Ice Thickness (R3)	Significance of ice freeboard observations remains to be established	Moored buoys (ONR)	High spatial resolution radar; develop. needed	Desirable, subject to operational viability	Possible with international/ commercial partners
Atmospheric Properties in Tropopause Region (R4)	Need ozone, water vapor, temperature at high vertical resolution	Sondes (WWW, NOAA)	Limb viewing sensors not yet demonstrated	Unlikely	Interest exists
Polar ice sheet velocity (R5)	Synthetic aperture radar interferometry; high latitude coverage (polar orbit) needed	GPS (NASA, NSF)	Demonstrated	Government /commercial partnership possible	Possible
Tropospheric Ozone and Precursors (R6)	Need excellent vertical resolution through entire troposphere, implies active lidar sensor	Airborne in situ for DC-8, R-2, WB-57	Experimental technique, needs further develop.	TBD	Interest exists

Table of Observational Parameters: Consequences

Parameter / Question	Implementation Details	In Situ Measurements	Technical Readiness	Operational Potential	Partnership Potential
Global Precipitation (C1)	Requires Constellation for Good Time Resolution	raingauges, weather radar (NOAA, WWW)	Demonstrated via TRMM	Limited	Excellent – several needed
Ocean Surface Winds (C1)	Active µwave technique	ships, buoys (NOAA, WWW)	Demonstrated by NSCAT and SeaWinds	NPOESS need nominally fulfilled by passive sensor	Seawinds cooperation with Japan; EUMETSAT
	Passive µwave radiometry/polarimetry probably sufficient for meteo. applications.		Windsat/Coriolis demonstration funded by DOD, USN, NPOESS	NPOESS commitment	Possible
Meteorological Properties Around Storms (C1)	Requires vertical profiling from a geostationary platform	Radiosondes (NOAA, WWW)	Demonstration planned with GIFTS	May become operational GOES sensor if successfully demonstrated	Possible
Lightning Rate (C1)	Requires geostationary implementation for temporal resolution	Sferics	Demonstrated by OTD and LIS	Could be implemented on future GOES	Possible
River Stage Height/ Discharge Rate (C1)	Requires high precision, vertical resolution, and frequent sampling	River gauges (USGS)	Capability demonstrated by Topex/Poseidon	TBD	TBD
Primary Productivity (C2)	1 km or better resolution needed	NASA-SIMBIOS, GOOS, GTOS, crop, forest inventories (USDA, FAO), LTER (NSF)	Excellent	NPOESS Commitment	EUMETSAT coordination
Land Cover / Land Use Change (C2)	High spatial resolution (few meters) crucial	Land cover maps (USGS), veg. Inventories (DOI, USDA)	Excellent, need to reduce cost	Commercial data purchase likely	Possible with US industry
Coastal Region Properties and Productivity (C3)	Multispectral radiometry at high spatial and temporal resolution from GEO	Coastal observations (NOAA, EPA)	Excellent	Could be implemented on future GOES	Possible